CHAPTER 4

WSR-88D FUNCTIONAL OVERVIEW

4.1 Introduction. The meteorological situation determines the WSR-88D volume coverage patterns, measurement accuracy requirements, and analysis products required for maximum information extraction. The user must understand the physical processes that take place within the WSR-88D unit in order to optimize this information extraction.

The foundation for quantitative meteorological radar measurements was established in Chapters 2 and 3. Mathematical formulations were given describing the translation from the physics of radar sensing to a series of sensible meteorological measurements used for mapping the structure, motion, and magnitude of areas of precipitation. These concepts are the theoretical building blocks for utilizing the WSR-88D.

4.2 Simplified Radar System. The WSR-88D unit is configured functionally in three areas with functions as shown in Figure 4-1. (A description of the WSR-88D is given in Part D of this Handbook).

- The RDA detects and estimates the meteorological phenomenon.
- The RPG performs the meteorological data analysis and reformats the output products for remote display.
- The user display system provides the user interface.

Using the system nomenclature just described, the following sections trace the data from meteorological detection through the RDA, RPG, and the user display system. The focus is on signal flow and the step-wise processing of data.

4.3 Radar Data Acquisition. A block diagram of the RDA is shown in Figure 4-2. For purposes of signal flow, this function is divided into three areas: 1) antenna, transmitter, and receiver; 2) signal processing; and 3) data preprocessing.

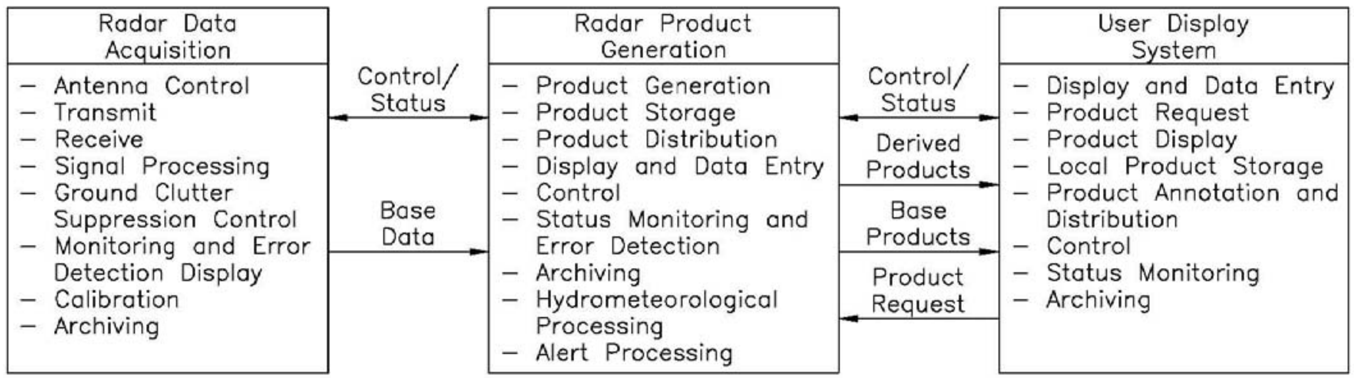

Figure 4-1
Functional Configuration of the WSR-88D Unit

The three major functional areas of the WSR-88D are shown along with the major data and messages transmitted among the functional areas.

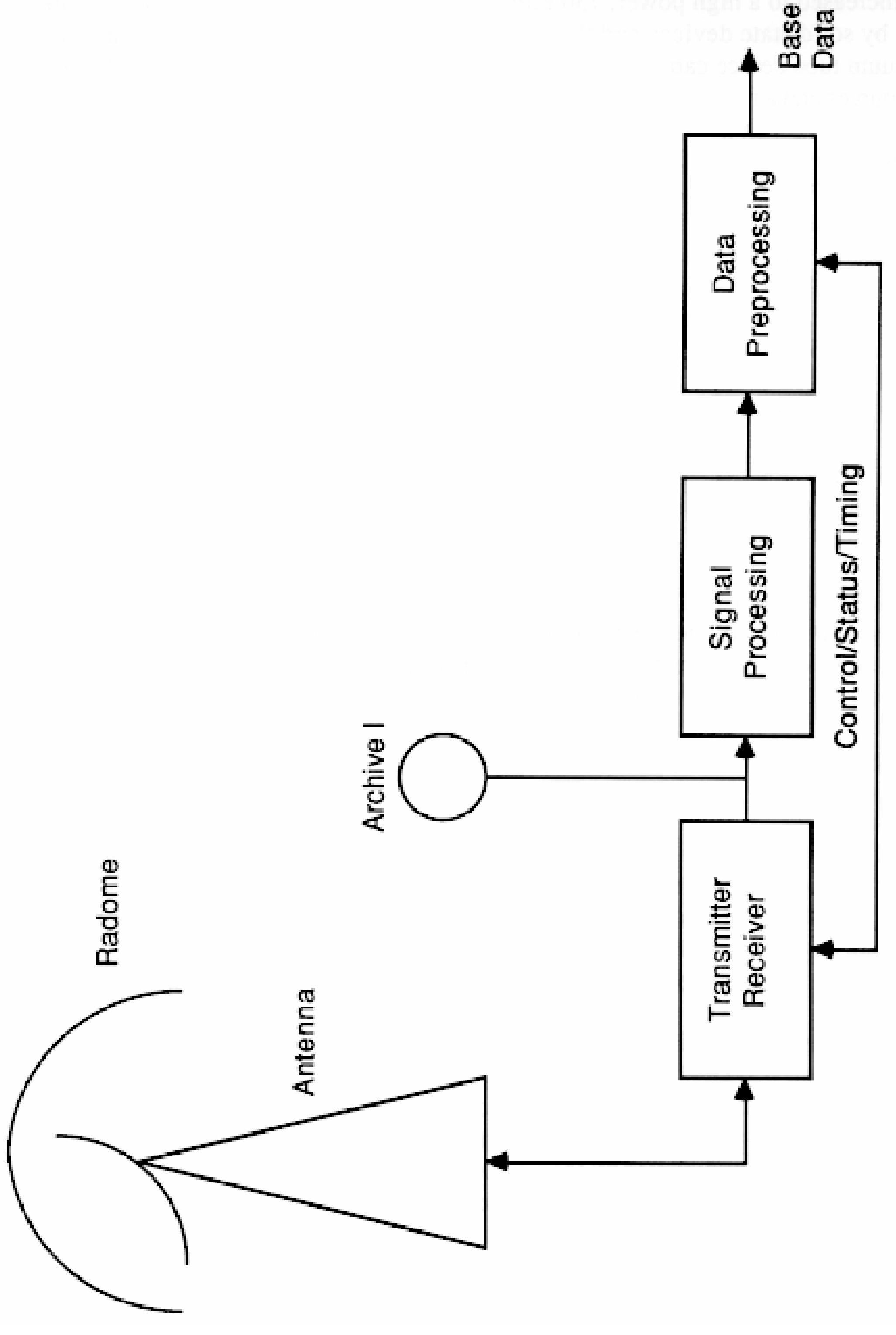

Figure 4-2
Block Diagram of the RDA

A complete tabulation of the radar system characteristics is given in Chapter 2. Some of the more important are: transmitter peak power of 750 Kw; a pulse width of 1.57 μs for the Precipitation Mode and 4.5 μs for the Clear Air Mode; and pulse repetition rates from about 300 to 450 Hz for surveillance and from about 1000 to 1300 Hz (short pulse) or 450 Hz (long pulse) for Doppler. The antenna main lobe one-way 3 dB beamwidth is 0.93 degree and the first sidelobe level is about 29 dB below the main lobe. The receiver has a dynamic range of about 100 dB and a bandwidth of 0.6 MHz. The radar system can detect a reflectivity of -8 dBZ_e at 27 nm (70 km), Figure 2-1, as per design, while actual tests indicate a somewhat better capability.

4.3.1 Basic Radar. The basic radar (antenna, transmitter, and receiver) is a coherent "chain-transmitter" design. Coherence, or phase information, in this design is maintained by very stable signal sources that operate continuously. These sources are used as the reference in extracting the Doppler shift of the back-scattered signal. A chain transmitter is one in which the transmitter signal is initially generated at a low power level, in this case a few hundred milliwatts, and increased to a high power, 750 kilowatts, by an amplifier chain. Intermediate amplification is by solid-state devices and the final high-power amplifier is a klystron. The klystron is a vacuum tube device capable of high amplification and efficiency. The WSR-88D uses two signal sources and a mixing scheme to generate the transmitter signal.

The receiver uses two frequency mixers to down convert the received signal to zero frequency carrier (video signal). The first conversion generates an intermediate signal carrier at which most amplification, bandpass filtering, and AGC are done. The second frequency conversion is synchronous detection (a detection that retains received signal amplitude and phase shift difference between received and transmitted signal phases but that removes the intermediate frequency carrier). This is a "complex" signal; complex meaning that it contains both amplitude and phase information and, for convenience of handling and analysis, is decomposed into its vector components, i.e., two signals (inphase and quadrature) having a phase difference of 90° that, when added vectorally, form the complex signal.

At this point the signal is still analog and carries the meteorological information as signal power, which is proportional to reflectivity, and the time rate of change of signal phase is proportional to target radial velocity.

4.3.2 Signal Processors. The "dedicated" signal processors calculate the electrical properties and translate them to the meteorological quantities of interest. Dedicated digital processors are processors designed and configured to perform a specific operation by implementing a specific algorithm with only limited changes in parametric values.

Reflectivity, Z, is estimated for each range interval from a linear average of several return pulses, usually about 25.

Velocity, v, is also estimated from an average of several pulses, usually 40 to 50. The mathematical quantity computed is the covariance of the return complex signal using a technique called "pulse-pair processing." The computation operates on two pulses (two consecutive signal returns from the same target). Physically, the covariance measures the rotation rate of the complex vector and represents the returned signal, which is directly related to the Doppler frequency.

Spectrum width, W, is estimated indirectly. The computation performed is the autocorrelation of the returned signal, which is related to the velocity spectrum standard deviation. It is also an average of the same number of pulses as the radial velocity. Physically the spectrum width is a measure of velocity dispersion within the radar sample volume. The signal from regions designated as being in the ground clutter by the site dependent clutter map is processed by a clutter filter that removes the clutter signal without serious degradation of the meteorological signal.

A comprehensive description of the signal processing and system performance is given in Chapters 2 and 3 and Appendices A and B.

4.3.3 Post Processing. Post-processing operations prepare the data for meteorological analysis and consist of unit conversion (from the normalized units used in signal processing to meteorological units used in analysis); specialized, highly redundant processing such as point target censoring and signal thresholding; and data conditioning such as range unfolding and velocity dealiasing.

Unit conversion consists of the following: signal power is converted to reflectivity by solving the radar equation for backscattering by hydrometeors (Appendix A.1); vector rotation rate is converted to velocity by multiplication by a constant derived from the Doppler equation, radar wavelength, and pulse repetition time; and spectrum width is converted from autocorrelation to velocity by multiplication by a constant derived from the radar wavelength and pulse repetition time under the assumption that the spectral density functional form is Gaussian (Appendix A.4).

Point target suppression is accomplished by an analysis routine that monitors the width and reflectivity gradient of the target and suppresses the return when these characteristics correspond to those of a point target.

Data thresholding consists of suppression of data points whose signal-to-noise ratios (2 dB for reflectivity and 3.5 dB for velocity and spectrum widths) fall below a user-specified value.

Range unfolding is achieved in the following manner. The occurrence of overlaid echoes (two or more echoes appearing at the same range due to the short unambiguous range of a high PRF) is detected by implementing a low PRF surveillance, range unambiguous, waveform along with the higher Doppler waveform. Determining the potential range ambiguities is accomplished by comparing power returned on a gate-by-gate basis for the higher Doppler PRF using the range unambiguous surveillance waveform. If the relative power of two or more potentially ambiguous range gates is within a user-specified difference (usually 5 dB), both echo regions are flagged as obscured and the Doppler velocities are suppressed for those same range gates. If the relative power is greater than the specified difference, the Doppler velocity and spectrum width data are assigned to that range gate having the greater power. The gate(s) having weaker power returned are then flagged as obscured and Doppler data is suppressed for those same gates.

The range-unfolding scheme is illustrated pictorially in Figure 4-3. Figure 4-3A shows the true range distribution of echoes as monitored by the reflectivity PRF [range folding is rare at this PRF with an unambiguous range of about 248 nm (460 km)]. Figure 4-3B shows the range distribution of normalized power (intensity) levels after folding where all echoes appear within the Doppler unambiguous range. Figure 4-3C shows the results of the range unfolding and suppression of data obscured by echo overlaying (in this case, echo 2 and echo 3).

Velocity dealiasing is accomplished by testing for velocity continuity along the radial and assuring true velocity gradients on the order of the Nyquist velocity co-interval, $\pm 2v_a$ do not exist. The measured velocities are checked gate-to-gate and measured differences greater than a specified value are assumed to be due to velocity aliasing. These large gradients are then reduced by adjusting the measured point velocity by $\pm 2v_a$ i.e., the radial velocity gradient is minimized by adjusting the measured adjacent range velocity values by $\pm 2v_a$ (Chapter 2).

The velocity dealiasing scheme is illustrated pictorially in Figure 4-4. Aliasing (Figure 4-4A) is recognized (Figure 4-4B) by velocity differences between adjacent range gates approaching $\pm 2v_a$. A running correction is made (Figure 4-4C) on all cells exhibiting this large velocity gradient by either adding $2v_a$ or subtracting $2v_a$ so as to minimize the gate-to-gate velocity difference.

4.3.4 Operational Scenario. The mode of radar operation is an automatic scanning sequence that provides the volumetric data for meteorological analysis. There is the design capability to have up to 20 predetermined volume coverage patterns available to the user allowing the data acquisition scheme to be varied with the meteorological situation.

There are several considerations in the selection of a data acquisition scheme (Chapter 3) with the governing considerations being the temporal and spatial scales of the meteorological situation (volumetric throughput rate) and the volume in space over which data are to be acquired (number of elevations). These two general considerations combine to specify the optimum antenna scan rate and, thus, dwell time for the data on the fixed 1° polar grid. Dwell time determines the system performance in terms of estimate accuracy, and estimate accuracy determines the quality of the output products.

The fastest acquisition scheme (VCP 12) is 14 unique elevations extending to 19.5° in a total time of 4.2 minutes. There is more than one scan at the lower elevation angles; the number of elevation angles is VCP dependent. A surveillance scan is made to obtain power return and target location information. A Doppler scan is made to obtain good velocity and spectrum width estimates. More samples of the atmosphere are obtained to provide better estimates of the three moments and to mitigate the effects of the Doppler Dilemma. Antenna rotation rate is dependent on number of elevations and the volume throughput time and may vary with elevation angle with maximum rates of about 5 revolutions per minute (rpm).

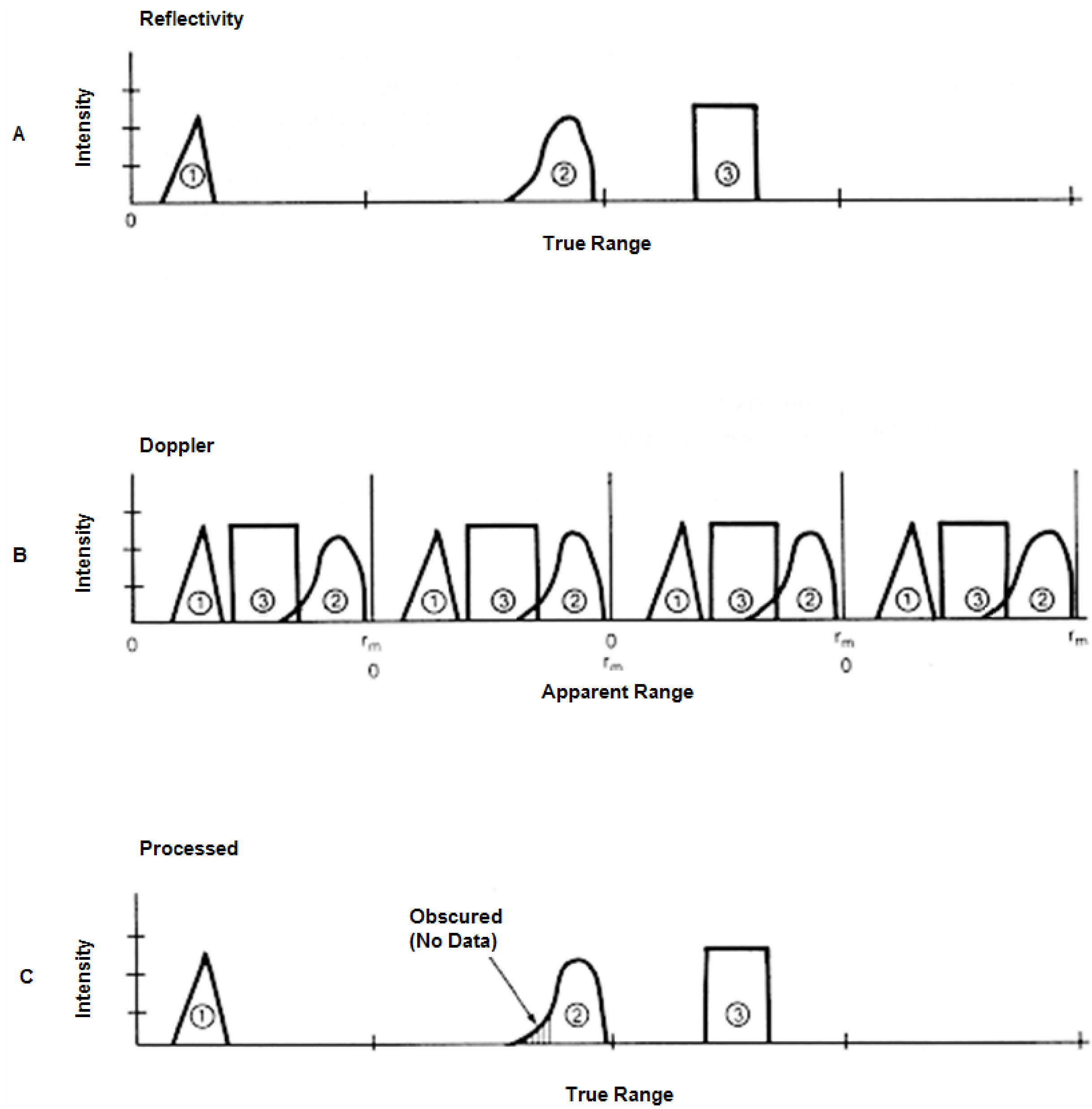

Figure 4-3
Range Unfolding/Obscuration Pictorial

See the text for a summary of the range-unfolding scheme operation.

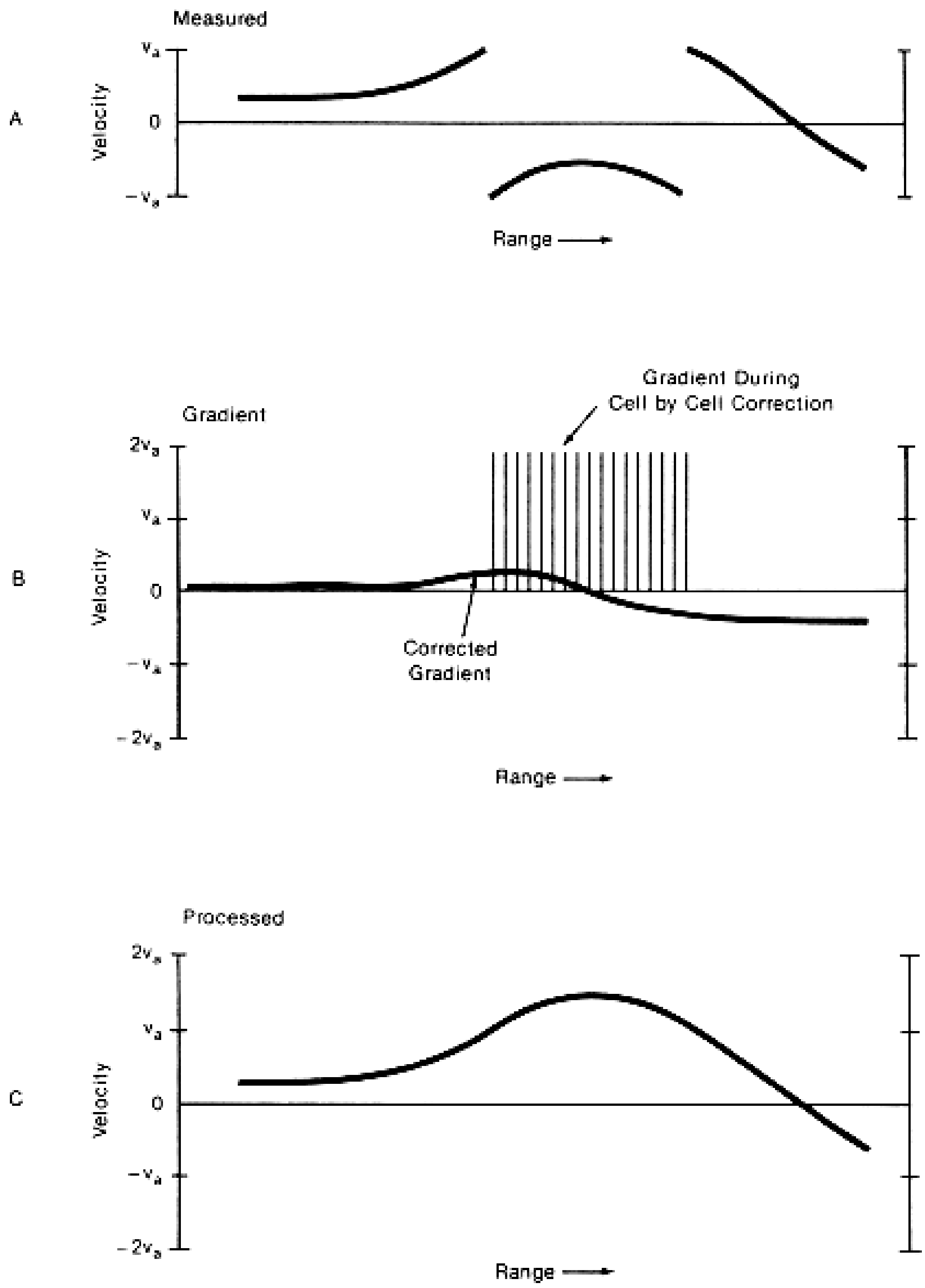

Figure 4-4
Velocity Dealiasing Pictorial

See the text for a summary of the velocity dealiasing scheme operation.

The transmitter PRFs are coupled to the scanning sequence providing long-range surveillance data at the low elevation angles where range folding is likely to occur and automatic selection of Doppler PRF (from the three choices available) that results in the minimum obscured echo area.

A representative fast scan sequence (VCP 12) is described in Table 4-1. The Batch Mode (B) technique uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. (See Part C, Chapter 5, of this Handbook for discussions of "Batch" processing). The low PRF long-range surveillance is provided by redundant scans at the lower elevation angles, where the altitude of the maximum Doppler range is less than about 50,000 ft (15 km). The Doppler PRF is selected from minimum obscuration consideration from the preceding volume scan and is fixed for the sequence (may change from volume scan to volume scan). The average rotation rate is 4.1 rpm, but varies from scan to scan in order to optimize system performance. For example, ground clutter suppression would be enhanced and measurement accuracy increased by rotating slower at the low elevation angles (Figure 3-6) but at the expense of increased error with the faster rotation rates that become necessary at the higher elevation. Considerable versatility is available in the unit within the meteorological and performance constraints given in Chapters 2 and 3.

4.3.5 Base Data Summary. Data sent from the RDA (base data) to the RPG consist of estimates of the first three Doppler spectral moments Z, v, and W. Data are delivered to the RPG (Figure 4-1), radial-by-radial, spaced approximately 1° apart. Time between data blocks for adjacent radials is determined by the acquisition scan rate and usually varies between 39 and 166 milliseconds. In addition to the auxiliary or housekeeping information, each block consists of three data subsets (Z, v, W) each containing about 1024 entries corresponding to the individual range cells.

General characteristics of the base data are given in Table 4-2. Reflectivity products are now limited to displays of -28 dBZ and up to greater than +75 dBZ. In actual observations values as low as -30 dBZ have been observed (commonly) and rarely values as high as about +78 dBZ have been observed. In reality these are probably near the atmospheric limits.

With the default velocity resolution setting of ~ 1 kt (0.5 ms^{-1}), the RDA is limited to observing velocities within the range of +/- 123 kts (+/- 62 ms^{-1}). Thus, this would be a base data limitation. However, when wind speeds (and therefore velocities) in tropical storms or in other particular cases are expected to exceed these limits, the velocity resolution can be expanded by setting the RDA velocity resolution default to ~ 2 kts (1 ms^{-1}). In this case the system is then capable of measuring +/- 246 kts (+/- 126 ms^{-1}). The system in actual practice has already measured velocities in excess of 130 kts (67 ms^{-1}). There will probably be occasions when actual meteorological measurements will at least approach 246 kts (126 ms^{-1}). However, velocity products will have to be modified for display of such values. Therefore, base data characteristics may reach this value.

Table 4-1
Representative Fast Scan Sequence (VCP 12)

			Unambiguous Range		*Unambiguous Velocity		
Scan	Elev	PRF (Hz)	nm	km	kts	m s^{-1}	Data
1	0.5°	322	252	466			Surveillance
2	0.5°	1014	80	148	49.4	25.4	Doppler Moments
3	0.9°	322	252	466			Surveillance
4	0.9°	1014	80	148	49.4	25.4	Doppler Moments
5	1.3°	322	252	466			Surveillance
6	1.3°	1014	80	148	49.4	25.4	Doppler Moments
7	1.8°	1014	80	148	49.4	25.4	Batch
8	2.4°	1014	80	148	49.4	25.4	Batch
9	3.1°	1014	80	148	49.4	25.4	Batch
10	4.0°	1014	80	148	49.4	25.4	Batch
11	5.1°	1014	80	148	49.4	25.4	Batch
12	6.4°	1014	80	148	49.4	32.1	Batch
13	8.0°	1905	74	137	53.3	27.4	Doppler Moments
14	10.0°	1181	69	127	57.5	29.6	Doppler Moments
15	12.5°	1282	63	117	62.4	32.1	Doppler Moments
16	15.6°	1282	63	117	62.4	32.1	Doppler Moments
17	19.5°	1282	63	117	62.4	32.1	Doppler Moments

* At λ=10 cm
Average rotation rate = 4.1 rpm
Dwell time = 39 milliseconds per degree
Doppler Moments = Contiguous Doppler waveform
Batch = Alternating low and high PRFs on each radial for one full rotation at each elevation angle.

Table 4-2
Base Data Characteristics

Data	Dynamic Range	*Estimate Standard Deviation	Range Coverage	Range Increment	*Data Resolution
Z	< -28 to > +75 dBZ	1 dB	0 to 248 nm (0 to 460 km)	0.54 to 248 nm (1 to 460 km)	0.3 dB
	**		***		
v	> +/- 123 kts (> +/- 62 ms^{-1})	1.9 kts (1 ms^{-1})	0 to 124 nm (0 to 230 km)	820 ft (250 m)	0.49 kt (0.25 ms^{-1})
			***		
W	0 to 35 kts (0 to 18 ms^{-1})	1.9 kts (1 ms^{-1})	0 to 124 nm (0 to 230 km)	820 ft (250 m)	0.2 kt (0.1 ms^{-1})

* typical value
** after velocity dealiasing and with a velocity resolution of about 1 kt (0.5 ms^{-1})
*** after range unfolding

4.4 Radar Product Generator. The digital base data generated within the RDA is sent via a wideband communications system (by fiber optics, wire, commercial T-1 circuits, or microwave line of sight) to the RPG where a larger computer system digests the full 3-dimensional volume of polar scan data.

As shown in Table 4-2, the reflectivity data are in a matrix of 360 degrees by 248 nm (460 km) in range; whereas the radial velocity data are in a matrix of 360 degrees by 124 nm (230 km) in range. The resolution of the reflectivity data is 0.54 nm (1 km); the velocity and spectrum width resolution is 0.13 nm (0.25 km or 820 ft).

The RPG computer system processes more than 250,000 lines of code to produce and transmit meteorological products. These products are derived from algorithms that enjoin several fundamental relationships among reflectivity and radial velocity patterns to provide users with conclusions concerning the locations, movement, and severity of meteorological phenomena.

4.4.1 Interactive Control. The control of the WSR-88D unit is linked through software resident in user terminals. The Master System Control Function (MSCF), a graphical user interface, is used to set all adjustable parameters that determine pulse repetition frequency, antenna motion, and all processing thresholds and limits, including the setting of adjustable parameters that affect the seasonal and geographical performance of the hydrometerological algorithms.

The RPG controls all analysis procedures. The products generated from the algorithms are queued, according to operational priorities, and sent to requesting displays at user workstations.

4.4.2 Meteorological Analysis Products. The graphic products are displayed after the analysis of multiple data fields in the RPG. Several of them are made directly from the polar scan data. For example, the base products of reflectivity, radial velocity, and spectrum width are truncated and scan converted to produce polar matrices [reflectivity, 0.54, 1.1, or 2.2 nm (1, 2, or 4 km) x 1^{o}; velocity and spectrum width, 0.13, 0.27, or 0.54 nm (0.25, 0.5, or 1 km) x 1^{o}] that can be color coded or grey-scaled to enhance their operational use. Other products are generated after analysis algorithms composite the data geometrically into layers, or transform them to other identities--such as shear, which is derived from the velocity field. Still other algorithms search the base data for specific reflectivity and velocity signatures that, when found, mark the hazards to be depicted as symbols or alphanumeric labels on the user display systems. Critical data thresholds are established and data is filtered for all products limiting displays to what is believed to be noise free and accurate data.

Products can be grouped generally into three areas of application: 1) Wind Profiling--which includes the measurement of wind velocity and shear in the optically clear boundary layer, in dense cloud layers that contain only extremely light precipitation, and in areas of heavy rain in stratiform and convective storms; 2) Precipitation Measurement--which includes quantitative data gridded for mapping on the national scale, and localized data that will allow local meteorologists and hydrologists to project the movement of areas of precipitation over specific watersheds; and 3)

Storm Warning--which provides location and tracking information on severe thunderstorms and estimates the likelihood of hail and tornadoes.

4.5 **User Display Systems**. The users of WSR-88D data have developed their own systems to display meteorological products generated by the RPG. A summary of the current systems in place to meet unique NEXRAD agency user needs is provided in Part D, Chapter 2, of this Handbook.

The original WSR-88D baseline display system, deployed to all NEXRAD agency user locations, was the Principal User Processor (PUP). The last of the PUPs will be decommissioned in 2006. The PUP has been replaced by an open-systems based architecture version termed the Open PUP. The Open PUP is considered the new WSR-88D baseline display device and is used by the ROC for implementing new product displays. Only DoD users operate the Open PUP.

REFERENCES

JSPO Staff, 1980: *Next Generation Weather Radar (NEXRAD) Joint Program Development Plan*, JSPO report. Silver Spring, MD, 102 pp.

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